EM Radiation Analysis of Electrical Dipole in Close Vicinity of Dissipative Object

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Abstract— A phenomenon of electromagnetic wave propagation produced by a GSM mobile phone antenna at the operating frequency 950 MHz, placed in close vicinity of a dissipative object has been investigated and measured. The model (phantom head) of a dissipative object representing and simulating electromagnetic properties of human head tissue in the GSM frequency band has been made. Dielectric properties of the phantom head have been measured. A GSM mobile phone antenna and GSM base station antenna were approximated with dipole antennas and adjusted to GSM frequency band. Radiation patterns and antenna efficiency of the GSM mobile phone antenna settled near the phantom head for vertical and horizontal polarization of the antennas have been measured and recorded on three specific frequencies inside the GSM frequency band.

Keywords- mobile communications; antenna; phantom head; antenna efficiency

I. INTRODUCTION

When studying interaction between electro-magnetic fields and biological subjects as the human head is, it is not possible to measure directly and harmlessly dissipative properties of the human head during the GSM communication and its influence on the radiation patterns and efficiency of GSM mobile phone antenna.

Some of the previous measurements included computer modeling of the human head [1] along with FDTD methodology derived from Maxwell’s time-domain equations [2] in order to indirectly measure the specific absorption rate (SAR) distribution of the EM energy that was dissipated in the human head during the simulated GSM communication, including the influence of the human head and handset model on the gain, efficiency and radiation pattern of the GSM mobile phone antenna.

Proposed investigation was motivated by the need for an efficient and fast method of determining mobile antenna efficiency in vicinity of the human body. In order to preserve human health or live organism in general when measuring EM radiation and effects, we made a phantom head – a liquid mixture that represents dielectric properties of the real human head tissue. Among quite different antenna types employed in modern mobile phones and terminals [3-6], we chose a simple half wavelength dipole antenna.

The main goal of this experimental and theoretical investigation is to observe the interaction of the human head with GSM mobile phone antenna, and the influence of the human head to the radiation patterns and radiation efficiency of the antenna. In that sense we also developed a measurement setup for simple and efficient measurements antenna measurements.

II. PHYSICAL MODEL OF THE HUMAN HEAD

The dielectric properties of the tissue with a great volume percentage of water (for e.g. muscle tissue and most of the organ tissues in the human body and head), in the frequency band from 1 MHz to 2 GHz are mostly defined by the dielectric properties and amount of water and salts dissolved in the tissue. These organs and tissues rich with water have relatively high values of the conductivity and permittivity ($\varepsilon_r \approx 50$, $\sigma \approx 1 \text{ S/m}$), which results in a pretty high reflection and attenuation of the incident EM wave (approx. 230 dB/m).

Liquid mixture (phantom of the human head tissue) for GSM frequency band, used in this research, was made according to the instructions in [7] and [8]. For liquid phantoms, the electric permittivity is controlled by adding proper amount of consumable sugar because sugar has very low specific permittivity (see TABLE I). For controlling electric conductivity of the phantom, sodium chloride (NaCl) is used in all cases.

| TABLE I |
|---|---|
| Ingredients | Net mass |
| distilled water | 2.00 kg |
| sugar (crystal consumable white) | 2.89 kg |
| consumable salt (NaCl) | 34.45 g |
| TOTAL | 4.92 kg |
The right amounts of ingredients for the phantom used in the measurements were calculated from [8].

The phantom is made and measured at the constant room temperature (22° C) in order to make measured dielectric properties more similar to the properties of the real tissue close to the body temperature.

### A. Measurement of Phantom Properties

Measuring dielectric properties of the phantom was performed according to non-destructive in vivo method developed by Mosig [9]. The measurement setup consisted of a coaxial probe and the network analyzer that measures reflection parameters on the probe connector. The probe itself is a 50 Ω open-ended semi-rigid coaxial cable filled with the teflon dielectric. The reflection coefficient is measured with the HP 8720B network analyzer calibrated via standard calibration procedure with three known loads at the plane of the probe connector. However, an error box appears between the probe connector plane and probe open-end plane [4]. In order to take into account this error box, three additional reflection coefficient measurements of known loads are necessary: open end, short circuit and distilled water (the dielectric constant of distilled water, as a function of frequency and temperature, is well known [5]). With these measurements the s parameters of the error box are determined.

\[
S_{11} = \frac{\Gamma_{OE} \Gamma_{SC} \Gamma_{H2O} (s_1 - s_2) + \Gamma_{OE} \Gamma_{H2O} \Gamma_{SC} (s_2 - s_1) + \Gamma_{OE} \Gamma_{SC} \Gamma_{H2O} (s_3 - s_1)}{\Gamma_{OE} \Gamma_{SC} (s_1 - s_2) + \Gamma_{OE} \Gamma_{H2O} (s_2 - s_1) + \Gamma_{SC} \Gamma_{H2O} (s_3 - s_1)}, \tag{1}
\]

\[
S_{22} = \frac{\Gamma_{H2O} (s_2 - S_{11}) - \Gamma_{SC} (s_3 - S_{11})}{\Gamma_{SC} \Gamma_{H2O} (s_2 - s_1)}, \tag{2}
\]

\[
S_{12} S_{21} = S_{21}^2 \frac{(S_{11} - s_2) + (1 - S_{22}) \Gamma_{SC}}{\Gamma_{SC}}, \tag{3}
\]

where \(s_1, s_2, \) and \(s_3\) are the measured reflection coefficients of three known loads with the true reflection coefficients \(\Gamma_{OE}, \Gamma_{SC}\) and \(\Gamma_{H2O}\), respectively. The true reflection coefficient \(\Gamma_p\) of the phantom is then related to the measured reflection coefficient \(\Gamma_M\) as follows:

\[
\Gamma_p = \frac{\Gamma_M - S_{11}}{S_{22} \Gamma_M + S_{12} S_{21} - S_{11} S_{22}}. \tag{4}
\]

Permittivity \(\varepsilon_r\) of the tested phantom can be directly calculated from the reflection coefficient \(\Gamma_p\) as a function of frequency \((\omega)\) by a relation:

\[
\varepsilon_r = \frac{-2}{\omega C_0 Z_0} \frac{1 - |\Gamma_p|^2}{1 + 2 |\Gamma_p| \cos \arg (\Gamma_p) + |\Gamma_p|^2 - \frac{C_f}{C_0}}, \tag{5}
\]

where \(C_0 = 0.0022 \, \text{pF}\) and \(C_f = 0.001 \, \text{pF}\) represent characteristic capacitances of the probe at the room temperature (22°C), and \(Z_0 = 50 \, \Omega\) is characteristic impedance of the coaxial line.

Electric conductivity \((\sigma)\) of the phantom is represented with the following formula:

\[
\sigma = \frac{\varepsilon_r \omega C_0 Z_0}{1 - |\Gamma_p|^2}, \tag{6}
\]

which is a function of frequency, although the frequency dependence is not explicitly visible (the \(\Gamma_p\) coefficient is, in fact, a function of frequency).

![Figure 1. Phantom permittivity as a function of frequency](image1.png)

![Figure 2. Phantom conductivity as a function of frequency](image2.png)
measured results correspond very well with the previous results [9,10].

III. RADIATION PATTERNS OF AN ELECTRIC DIPOLE CLOSE TO THE PHANTOM HEAD

The $E$- and $H$-plane radiation patterns of an electric half-wave dipole that simulated the real GSM mobile phone antenna, near the phantom head have been observed and recorded.

The measurement setup, shown in Fig. 3, consists of two identical half-wave dipole antennas, a dissipative object (the phantom head) seating on a turntable close to the transmitting antenna, network analyzer, and a PC for data processing. Two half-wave dipole antennas are designed and manufactured in our laboratory for the GSM frequency band. A cylindrical shape of the phantom is chosen because we intended to make a comparison with the simulated results from the software package CyMPA developed in our laboratory, which uses MoM in spectral domain [11]. Transmission parameters are corrected using return loss data via $S_{11}$ and $S_{22}$. The influence of the reflections from the nearby objects is reduced using time domain reflectometer option of the network analyzer.

The measurements were performed in the frequency range from 900 to 1000 MHz for the phantom spacing 0, 1, 2 and 5 cm from the receiving antenna. The measurement procedure explained above was performed for vertically and horizontally polarized antennas, which makes different radiation patterns shown in Figs. 4-9.

Figs. 4 and 5 show that the $H$-plane radiation pattern of the vertically polarized antenna at 950 MHz frequency is closer to the cardioid as the distance between the antenna and the phantom is gradually increasing. For the horizontally polarized dipole, radiation patterns show similar effects. It is obvious that the presence of the phantom splits the back lobe into three smaller separated back lobes and for the distance between the transmitting antenna and the phantom greater than 2 cm, the ‘front’ lobe is somewhat increased probably due to reflection phenomena at the phantom.

Radiation patterns in the $E$-plain are narrower as shown in Figs. 6 and 7. Maximal radiated power for the phantom spacing of 5 cm is greater than that for the dipole alone. This should be prescribed to the effect of the phantom as an reflector in that configuration.

Figure 4. A comparison between 950 MHz measurements and a theoretical prediction of the $H$-plane radiation patterns for a dipole parallel to the phantom axis

Figure 5. A comparison between measurements and a theoretical prediction of the $H$-plane radiation patterns for a dipole parallel to the phantom axis (polar plot at 950 MHz)

By using an extrapolation technique, a simple 3D radiation pattern was constructed do determine the dipole antenna efficiency in the presence of the human head phantom. The 3D radiation pattern was extrapolated using a simple formula

$$F(\theta, \varphi) = F_H(\theta) \sin^2 \varphi + F_E(\theta) \cos^2(\varphi),$$  \hspace{1cm} (7)
where \( F_H(\theta) \) and \( F_E(\theta) \) are 2D radiation patterns in two orthogonal planes.

Figure 6. A comparison between measurements and a theoretical prediction of the \( E \)-plane radiation patterns for a dipole parallel to the phantom axis; the dotted line corresponds to the case without phantom.

Figure 7. A comparison between measurements and a theoretical prediction of the \( E \)-plane radiation patterns for a dipole parallel to the phantom axis (polar plot at 950 MHz); the dotted line corresponds to the case without phantom.

Figure 8. A comparison between measurements and a theoretical prediction of the \( E \)-plane radiation patterns for a dipole perpendicular to the phantom axis (polar plot at 950 MHz).

Figure 9. A comparison between measurements and a theoretical prediction of the \( H \)-plane radiation patterns for a dipole perpendicular to the phantom axis (polar plot at 950 MHz).

These radiation pattern measurements suggest substantial absorption of the electromagnetic energy into the phantom head. The absorption becomes greater as the distance between antenna and the phantom decreases. When the antenna is closest to the phantom (0 cm, the thinnest line on the diagrams), the EM absorption of the phantom increases, and takes value of less than 59% of the total radiated power for the horizontally polarized dipole and less than 42% for the vertically polarized dipole.
IV. CONCLUSIONS

The performances of an antenna placed in the proximity of a human head model have been investigated. A simplified experimental analysis of the EM radiation of the half-wave electrical dipole close to the phantom head in the GSM frequency band has been used. Measurements of the radiation pattern have been provided in two orthogonal planes. Based on a simple extrapolation formula, the radiation efficiency of a half-wave dipole antenna in presence of the human head phantom has been calculated from the radiation patterns measured in the $E$- and $H$-planes. Very good agreement between theoretical and experimental results has been found.

REFERENCES